PRODUCTION AND FIELD INSPECTION OF COMPOSITE AEROSPACE STRUCTURES WITH ADVANCED SHEAROGRAPHY

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INTRODUCTION

Shearography is a new NDT technology that has evolved from work in the 1960s and 70s in the area of laser holography. Sensitive to sub-microscopic deformations in the surface of a test object, shearography produces a video image of surface strain within a sensitivity typically on the order of 0.1 microstrain. Holography suffers from several inherent technical problems such as the requirements for high resolution film, isolation from environmental vibration as well as an image that requires experienced operators to interpret. Shearography has been quickly accepted into the NDT community because it substantially overcomes these inherent problems. Advanced shearography provides a real time video image of the displacement derivative field covering the area on the test object being observed.

Combined with an appropriate stressing mechanism, advanced shearography is capable of imaging the strain field around individual fiber bundles in composite materials or large areas measuring many feet on a side. Unlike holography systems that require the test part to be placed on a vibration isolation table along with the laser and optical components, shearography equipment has been manufactured that is small enough to be carried in one hand for use in performing the inspection of composite structures on-aircraft. This new capability can lead to large cost savings by eliminating costly tear-down of the aircraft during overhaul. In addition, the repair of composite aircraft structures can be verified easily and quickly. Present applications of advanced shearography include the production inspection of the B-2[1] and investigation of the quality of the repairs on F-18 graphite epoxy skins.

THEORY OF SHEAROGRAPHY

Shearography uses a laser operating in the visible light range to illuminate the area on the target with light through a fiber optic cable.

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[1] Air Force, Northrop Open B-2 Production Facility to Journalists, Aviation Week, June 25, 1990 Vol. 132, No. 26, pg. 22.

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 10B
Edited by D.O. Thompson and D.E. Chimenti, Plenum Press, New York, 1991

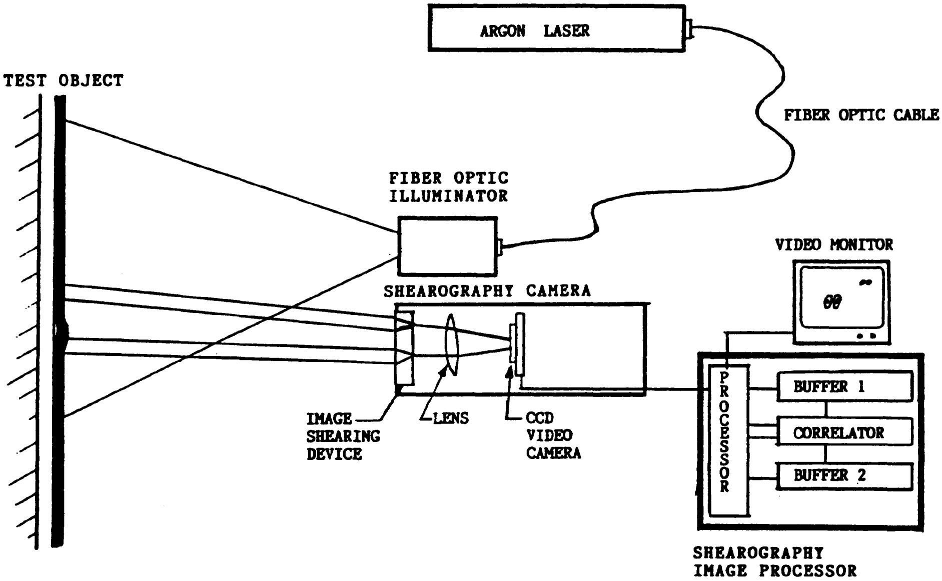

Fig. 1. Schematic Diagram of a Shearography System

An expansion lens helps the light to expand in a cone angle to illuminate the area of interest. Typical fields of view range from 2-3 mm square to a meter or more on a side. The reflected laser light is directed through a device to optically generate two identical images with a slight 1-2 degree offset angle or shear. These images are focused onto the video camera. At the plane of the camera, the images combine to form light intensity variations that result from the complex addition of the two coherent wave fronts.

A reference video image is stored in a computer buffer after which, every video image is subtracted from the reference image. If no changes occur to deform the object, the video monitor will remain black. Changes in the local shape of the object resulting from the uniform loading of the object with stress result in the formation of interference fringes on the field of view. These fringes map the derivative of the deformation and are centered on the points of maximum slope change for local deformations. Figure 1 shows a schematic diagram of a shearography system.

THEORY OF SHEAROGRAPHY NDT

The application of an appropriate and controlled stress to the test part is of critical importance to the detection of subsurface flaws. The volumetric strain field must be affected by the presence of the discontinuity and this affected field must reach to the surface of the test part. Hence, the success and reliability of shearography as an NDT tool is both material and geometry dependent. Table 1 shows the most useful stressing techniques and where they are most successful for a given flaw type.

TABLE 1

Stressing Techniques Used in Shearography Nondestructive Testing

Stress	Material	Defect Type Detected
Thermal	Graphite Epoxy	- Delaminations Panels - Impact damage - Some foreign material
	Honeycomb	- Skin to core debonds - Crushed core - Thermal expansion properties
	All Materials	- Thermal expansion properties
Vacuum	Graphite Epoxy	- Impact damage - Delaminations - Porosity
	Honeycomb	- Skin to core septum and far side debonds - Sheared core - Crushed core
	Rubber Bonded to Metal or Composites	- Debonds
	Foam Core Panels	- Both near surface and deep debonds
	Cork to Metal or Composites	- Debonds
Vibration	Honeycomb	- Skin to core debonds - Crushed core
	Foam to Composite or Metal Panels	- Debonds
Microwave	Materials with High Dielectric Constant	- Entrapped moisture

The sequence of the test technique can vary, however, usually the reference image is stored prior to the application of the stress. As the stress is applied, the real time image of the part on the video monitor shows the submicroscopic deformation of the part. The image is then frozen once the stress has reached the required stress level for the test. Thermal loading of materials with a high coefficient of thermal expansion can be tested by heating the object and observing the local deformation due to the flaw during cool down.

Microwave has been successfully used to detect entrapped water even in thin graphite skinned honeycomb panels. Due to the danger of exposure to microwaves, this technique must be used with extreme caution. Typical irradiance energy levels are 1-100 watts per sq. cm. depending upon thickness of the material and electrical conductivity.

PRODUCTION SHEAROGRAPHY INSPECTION

The use of shearography as a production tool requires equipment for applying the stress load on the part uniformly and with good repeatability. Vacuum loads are usually provided with a centrifugal blower and require typical pressure drops of 20-100 mm Hg. When using vacuum loads, it is important that the defect or the panel have no air leak paths that could equalize the pressure within the sample preventing detection of the flaw. Impact damage is detectable due to the absorption of air into the fractured matrix. This air expands when the part is inspected with vacuum loading, causing the damaged material to undergo a local deformation.

The use of fiber optic laser beam delivery keeps the laser in a fixed position, particularly important when a large ion, water cooled laser is used. In addition, the use of fiber optics to bring the laser light to the test part allows the use of a scanning multi-axis gantry to inspected large contoured panels. Shearography inspection does not require precise alignment of the camera with the test part, greatly reducing the costs of gantries for scanning when compared to ultrasonic C-scan inspection. With automated scanning and a fast pressure cycle, shearography systems can achieve an inspection throughput of as high as 30 square meters per hour for C-scan.

FIELD INSPECTION WITH SHEAROGRAPHY

Due to the insensitivity of shearography to environmental vibration and ambient temperatures, shearography can be an extremely useful field inspection tool for aircraft and large launch vehicles such as the Atlas Centaur[2] and the Space Shuttle. Being a single sided inspection technique, shearography lends itself to nondestructive testing of complete vehicles where access to the far side is impossible or costly. Such access is required for many other inspection techniques such as radiography and ultrasonics.

Again the use of fiber optics allows the designer to produce a small lightweight shearography inspection head that allows completely portable operation. Such equipment has been demonstrated on commercial aircraft for the inspection of honeycomb flaps and composite control surfaces.

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[2] NDT of An Adhesively Bonded Fixed Foam Insulation for Atlas/Centaur Cryogenic Fuel Tanks, Douglas D. Burleigh, NQNDE Conference, Bodin College, ME, July 15, 1989.

CONCLUSIONS

Advanced shearography has emerged as a powerful tool for the inspection of a large class of composite structures for both manufacturing and operationally induced flaws. Whole laser light is not a penetrating radiation. Shearography is sensitive to subsurface flaws in cases millimeters below the surface.

Shearography is also one of the first new technologies to provide a full field video inspection in real time of a part, instead of the point by point scanning required by ultrasonic C-scan. The growing use of shearography will help to contain costs in the manufacturing of composite structures and assure their long service life through nondestructive testing.